

RESEARCH NOTE

TASTE INTENSITY AS A FUNCTION OF STIMULUS
CONCENTRATION AND SOLVENT VISCOSITY

HOWARD R. MOSKOWITZ

*Pioneering Research Laboratory,
U.S. Army Natick Laboratories, Natick, Mass., U.S.A.*

and

PHIPPS ARABIE

Laboratory of Psychophysics, Harvard University, Cambridge, Mass., U.S.A.

Abstract. The method of magnitude estimation was used to determine how viscosities imparted by sodium carboxymethylcellulose affect the taste intensities of various concentrations of glucose, citric acid, sodium chloride and quinine sulfate. For almost all levels of concentration across the four substances, an increase in the viscosity of the aqueous solvent produced decreases in taste intensity. A power function with a negative slope was chosen to describe the relation between the apparent viscosity (V , in centipoises) and the taste intensity (T): $T = kV^{-n}$, where n varied between 0.05 and 0.20. The relation between the concentration of the sapid chemical and the taste intensity, in most instances, also conformed to a power function, although some deviations occurred at low stimulus levels.

1. Introduction

Several reviews have recently appeared on the use of thickening gums in foods (Glicksman, 1962; Klose and Glicksman, 1968, Szczesniak, 1963; Szczesniak and Farkas, 1962), but these papers concern primarily the rheology of the gums and deal far less with the effect that viscosity has upon the magnitude of taste intensity. Two earlier psychophysical studies by Mackey and Vallassi (1956) and by Mackey (1958) suggested that the solvent plays an important role in the detectability of tastes, with thresholds being considerably higher in gum and in lipid solutions as compared to water solutions. The physical form of the carrier was also shown to play a role; specifically, thresholds were lowest in water, and higher in foams and in gels.

Stone and Oliver (1966) investigated the relation between sweetness and viscosity for suprathreshold levels of sugar. They used five thickeners: cornstarch, gum tragacanth, carboxymethylcellulose, methylcellulose, and pectin, and confirmed Mackey's finding that sucrose sweetness was more difficult to detect in viscous solutions than in plain water. On the other hand, when observers were asked to rank order the two types of solutions according to sweetness, they rated the viscous solutions as being sweeter. Vaisey, Brunon and Cooper (1969) demonstrated that the rheological properties of the thickener predicted how it reduced the sensation of sweetness. They studied the effects of three gums: cornstarch, guar, and carboxyme-

* This paper reports research undertaken at the U.S. Army Natick (Mass.) Laboratories, and has been assigned No. TP 812 in the series of papers approved for publication. The findings in this report are not to be construed as an official Department of the Army position.

thylcellulose, and showed that the extent of sweetness reduction in the presence of the thickeners could be predicted from the curve relating the decrease in viscosity to the increase in shear rate. Cellulose gum most effectively diminished sweetness and showed the smallest decrease in viscosity with increasing shear rate, whereas the remaining two thickeners were less effective in reducing sweetness and showed larger decreases in viscosity with increasing shear rate.

The present study differs from the four previous ones in that it proposes a function relating the apparent solvent viscosity to the magnitude of taste intensity, with both variables measured along a ratio scale. In several previous studies, taste intensity (T) was reported to follow a power function of concentration (C): $T = kC^n$ (Moskowitz, 1968, 1970a, 1970b; Stevens, 1969). The exponent n governs how the magnitude of the subjective response grows with the concentration of the stimulus variable. The exponent for sourness and bitterness appeared to be about 1.0, indicating that the intensity of these two tastes is linearly related to concentration. Sweetness and saltiness grew approximately as the 1.3 to 1.4 powers of concentration, suggesting that their perceived sensory magnitude increased as a positively accelerating function of concentration (Meiselman, 1968; Moskowitz, 1968; Stevens, 1969).

The two areas of research covered in this paper are (1) the relation between taste intensity and stimulus concentration at different solvent viscosities, and (2) the relation between taste intensity and apparent viscosity for a fixed level of stimulus concentration. The present study concerns these two questions for the four primary tastes: sweet, sour, salty, and bitter.

2. Procedure

The effects of cellulose gum (7HOF, Hercules, Inc.) were investigated in two experiments in which observers sampled several concentrations of stimulus solution at four levels of solvent viscosity (1, 10, 100, and 1000 centipoises). All stimulus solutions were prepared with reagent-grade chemicals and distilled water. The solvent, a mixture of water and cellulose gum, was prepared at three levels of viscosity. The apparent viscosities were determined at 57 rpm with a MacMichael Viscometer (spindle insertion of 2 cm) and converted to centipoises with a calibration chart based upon the viscosity of glycerol.

The observers were enlisted men and scientists at Natick Laboratories, who were trained in the method of magnitude estimation by assigning numbers to match the lengths of lines and areas of circles drawn on index cards. In Experiment 1, eighteen observers judged the sourness of citric acid, and the same group plus one additional observer judged the sweetness of glucose. In Experiment 2 run several days later, twenty-two observers judged the bitterness of quinine sulfate and the saltiness of sodium chloride. Eleven observers from Experiment 1 also participated in Experiment 2.

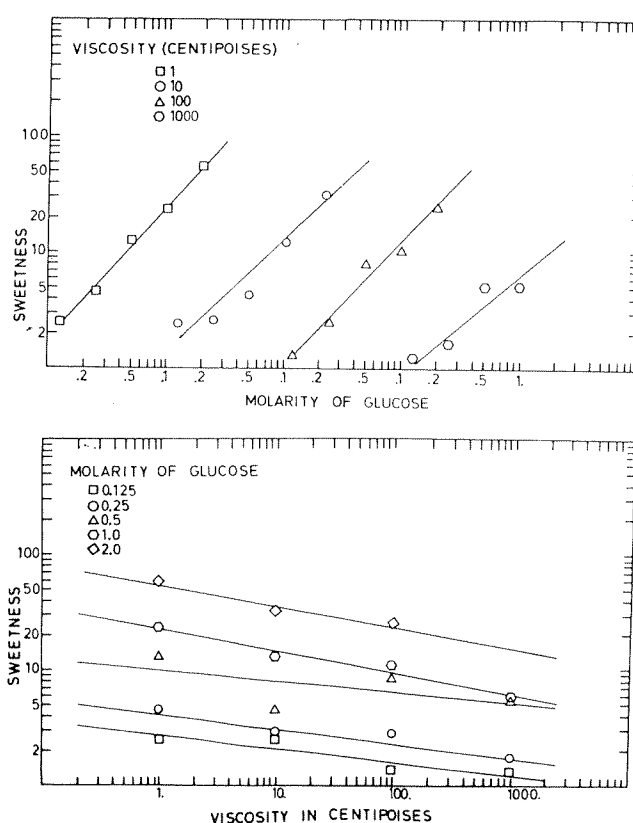
Each observer judged every solution only once per session. The stimuli were arranged in irregular order of concentration, in small paper cups containing 5–7 ml of solution. In both Experiments 1 and 2, observers tasted each of the solutions for

one taste modality prior to judging those for another. The order of precedence in presenting the modalities was reversed for half the observers, so that a balanced design was obtained. Test solutions were expectorated and not swallowed. Sessions lasted 20 to 30 min, during which time the observers sampled either 41 or 48 solutions.

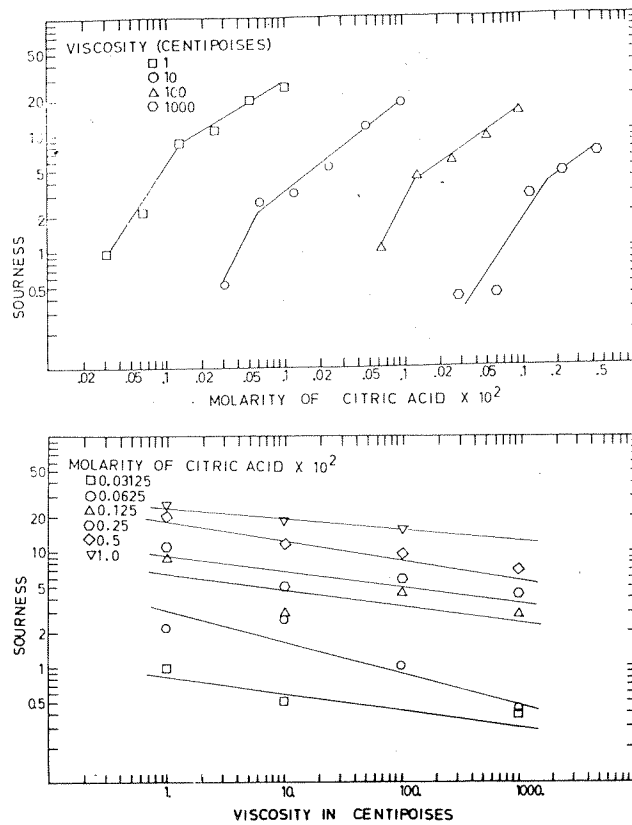
The observers were given the following written instructions:

"In front of you is a series of solutions in paper cups. Your task is to tell how _____ they seem by assigning numbers to them. If the second seems nine times as _____ as the first, assign it a number nine times as large. If it seems one-eleventh as _____, assign it a number one-eleventh as large, and so forth. Use decimals, fractions and whole numbers, but make each assignment proportional to _____. Rinse well between each sample, and if there is a residual taste in your mouth continue to rinse in order to remove it thoroughly".

The appropriate words were placed in the blank spaces for each taste, i.e., sweet, sour, salty, and bitter.



Figs. 1a, 1b. Sweetness as a function of molarity and viscosity. The coordinates are log-log, in which power functions are represented as straight lines. To facilitate comparison of functions in Figure 1a, each succeeding function has been shifted over by one logarithmic unit, so that the abscissa does not imply a continuum. The highest glucose concentration, 2.0 M, was not investigated at 1000 centipoises.



Figs. 2a, 2b. Sourness as a function of molarity and viscosity. The coordinates are log-log, and each succeeding function in Figure 2a has been shifted over by one logarithmic unit on the abscissa. Two concentrations of citric acid were not investigated, 0.003125 M at 100 centipoises, and 0.01 M at 1000 centipoises.

3. Analysis

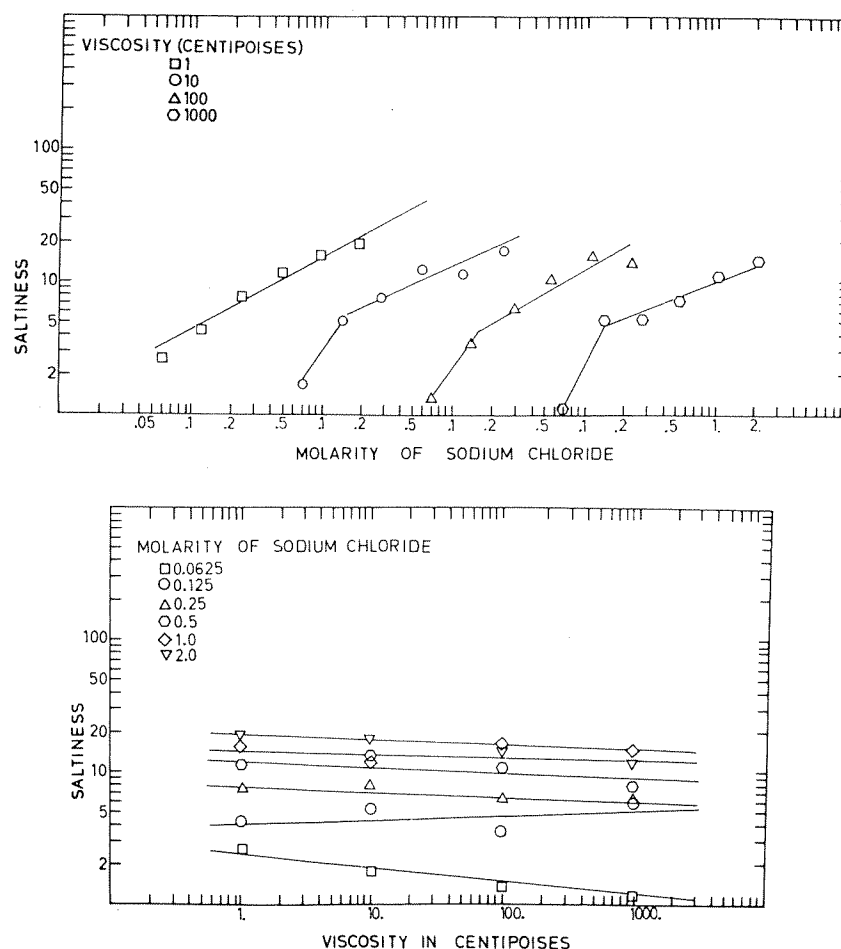
The magnitude estimates were analyzed with a computer program known as PSYCHOPOWER, which is an extensively revised version of PSYCHOFIT (Panek and Stevens, 1965). PSYCHOPOWER provides least-squares estimates of the exponent and the intercept of power functions fitted to both the geometric mean and the median magnitude estimates. Medians were used as a measure of central tendency, since observers often reported that several tastes were undetectable in solutions of high viscosity (primarily the lower concentrations of quinine sulfate).

Observers were free to select their own moduli (scale units), and the first stimulus (standard) could be any concentration in the series of stimuli. Some of the inter-observer variability in the judgments can be accounted for by the different moduli that result from this method, and much of the scatter resulting from discrepant moduli was reduced by the normalization procedure of *modulus equalization* (Lane

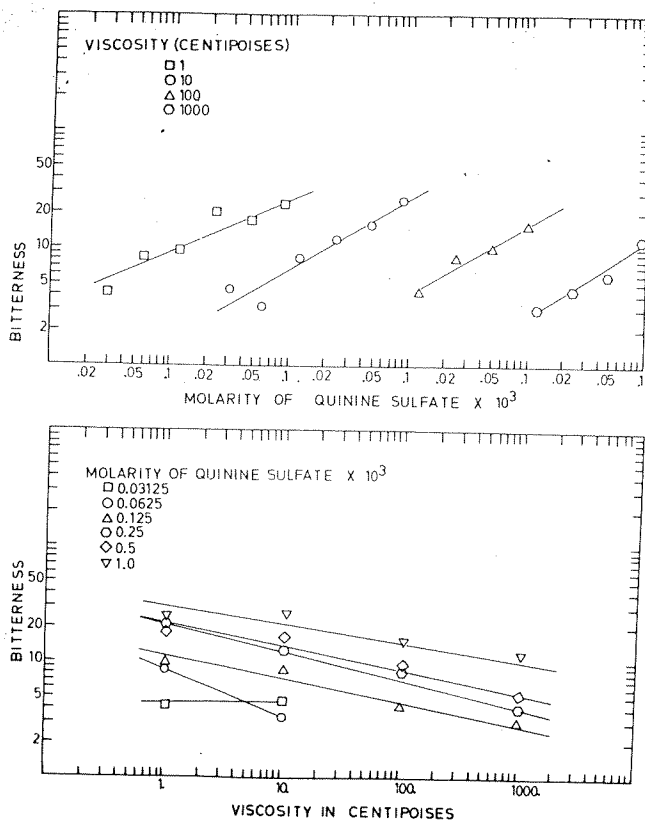
et al., 1961). The magnitude estimates for the entire set of stimuli of each taste were multiplied by the same constant (for a given observer), where the constant was the factor required to make the geometric mean of the estimates of each observer equal to the group mean. Thus, the modulus of each observer was brought into congruence with the group modulus, but no changes were made in either the ratios of magnitude estimates of a single observer, or in the slope of the sensory function in log-log coordinates.

4. Results

The sensory functions for the primary tastes are shown in four sets of two figures each. Figures 1a-4a present the taste intensity as a function of molar concentration, with the apparent solvent viscosity as the parameter. Figures 1b-4b present the



Figs. 3a, 3b. Saltiness as a function of molarity and viscosity. The coordinates are log-log, and each succeeding function in Figure 3a has been shifted over by one logarithmic unit on the abscissa.



Figs. 4a, 4b. Bitterness as a function of molarity and viscosity. The coordinates are log-log, and each succeeding function in Figure 4a has been shifted over by one logarithmic unit on the abscissa. The lowest concentrations of quinine sulfate, 0.00003125 *M* and 0.0000625 *M* were below threshold at 100 and 1000 centipoises.

same data with a different functional representation. The dependent variable is still the taste intensity, but the independent variable is now the apparent solvent viscosity, with the molar concentration of the stimulus held constant.

The coordinates of both sets of figures were chosen to be logarithmic. Power functions of the form $T = kC^n$ were, thus, rectified into straight lines with the slope given by the exponent n and the intercept given by the value of $\log k$. The power function, rather than the linear, logarithmic or exponential function, was selected to represent the sensory function because its exponent is a convenient parameter with which to measure the rate of growth of sensory intensity. The exponent can be compared across many different types of stimulus conditions (e.g., different levels of apparent solvent viscosity for each taste), and has the convenient property of being independent of the absolute magnitudes of both the response scale (modulus) and the stimulus measure. Thus, only the information left invariant by the change of stimulus and of response scales is of interest in the power relation, and it is precisely such in-

TABLE I
Parameters of the power function $T=kC^n$ relating taste intensity (T)
to molar concentration (C)

	Apparent Viscosity, cps	n	k	Pearson R^2
Sweetness				
1)	1	1.13	24.7	.99
2)	10	0.97	12.6	.92
3)	100	1.06	12.0	.97
4)	1000	0.79	6.0	.87
	Mean	1.01		
Sourness				
5a)	1	1.54	25,051.	.99
b)		0.56	364.	.97
6a)	10	2.34	87,119.	
b)		0.79	166.	.95
7a)	100	1.20	900.	
b)		0.61	242.	.99
8a)	1000	1.39	5,207.	.79
b)		0.63	194.	.998
	Mean a)	1.62		
	Mean b)	0.61		
Saltiness				
9)	1	0.59	15.1	.97
10a)	10	1.59	139.3	
b)		0.44	14.2	.93
11a)	100	1.40	63.1	
b)		0.55	13.1	.90
12a)	1000	2.27	614.2	
b)		0.38	10.5	.93
	Mean a)	1.76		
	Mean b)	0.49		
Bitterness				
13)	1	0.49	824.3	.90
14)	10	0.59	1,597.0	.91
15)	100	0.58	873.0	.95
16)	1000	0.64	850.0	.94
	Mean	0.58		

formation that is the primary result of direct magnitude scaling of sensory intensity.

The straight lines and the line segments in the figures represent power functions whose parameters (slope, intercept) and goodness-of-fit (Pearson R^2) are listed in Tables I and II. For those cases in which only two points constitute the function, R^2 is not given, since it is trivially equal to 1.00. The functions for the taste intensity of saltiness and sourness do not conform to simple power functions across the entire range of concentrations. For convenience in analysis, these have been broken into two nearly linear segments, which were then analyzed separately.

As a first approximation, the overall slopes for sweetness and bitterness, as well as the two sets of slopes each for sourness and saltiness, do not appear to undergo

TABLE II
Parameters of the power function $T=kV^n$ relating taste intensity (T)
to apparent viscosity (V)

	Molarity	n	k	Pearson R^2
Sweetness				
1)	.125	-.12	2.6	.85
2)	.25	-.14	4.2	.93
3)	.5	-.09	9.4	.34
4)	1.	-.21	22.5	.97
5)	2.	-.17	53.0	.94
	Mean	-.15		
Sourness				
6)	.0003125	-.12	.85	.85
7)	.000625	-.26	3.1	.84
8)	.00125	-.13	6.7	.58
9)	.0025	-.11	9.2	.68
10)	.005	-.15	18.8	.96
11)	.01	-.12	25.3	.95
	Mean	-.15		
Saltiness				
12)	.0625	-.12	2.4	.96
13)	.125	+.01	4.3	.63
14)	.25	-.06	8.2	.92
15)	.5	-.07	13.1	.68
16)	1.	-.04	15.5	.37
17)	2.	-.05	19.5	.90
	Mean	-.06		
Bitterness				
18)	.00003125	+.03	4.2	
19)	.0000625	-.40	8.7	
20)	.000125	-.18	10.7	.94
21)	.00025	-.22	20.9	.99
22)	.0005	-.17	20.4	.91
23)	.001	-.12	28.6	.82
	Mean	-.18		

systematic changes with increases in the apparent solvent viscosity induced by cellulose gum. Therefore, the growth rate of taste intensity with concentration seems to be unaffected by the presence of the gum. The obtained exponents are somewhat lower than the previously reported values for taste (Moskowitz, 1968). Presumably, this is a consequence of the restricted range of numbers given by the observers, which would tend to flatten the function in log-log coordinates.

The relation between the taste intensity and the apparent viscosity also appears to conform to a power function, although over the relatively short range of response magnitudes (approximately 0.5 log units) various other monotonic functions may account for the data equally well. All power functions fitted have negative slopes indicating that increases in apparent viscosity produce decreases in the perceived taste

intensity. The exponent denotes the rate at which the taste intensity is diminished by the apparent solvent viscosity. The obtained exponent values are between -0.1 and -0.3 . This indicates that an increase of ten logarithmic units ($10^{10}:1$) of apparent viscosity produces a perceived decrease of taste intensity around 1 to 3 log units ($10:1$ and $1000:1$, respectively). The present study suggests that this low rate of decrease imparted by the cellulose gum holds true for all four tastes, and that representation by power functions appears to be a convenient way of plotting such viscosity data. A previous study (Arabie and Moskowitz, unpublished) suggested that the decrease in sweetness for sucrose and saccharin also conforms to a power relation, with the exponent being between -0.2 and -0.25 .

Expressing relations between viscosity, stimulus concentration, and perceived intensity of taste as power functions appear to present a useful tool for assessing the effects that various types of thickeners have upon the taste system. The exponent, when used as an index of masking ability, can be employed to classify the differential effects of gums and lipids on each of the taste qualities. Furthermore, from a comparison of the relative values of exponents, one might further quantify the contention of Vaisey *et al.* (1969) about the relation between the effectiveness of taste masking and the rheological properties of thickening agents.

References

- Arabie, P. and Moskowitz, H. R.: 'The Effects of Viscosity Upon Perceived Sweetness', submitted to *Perception & Psychophysics*.
- Glicksman, M.: 1962, 'Utilization of Natural Polysaccharide Gums in the Food Industry', in *Advances in Food Research* Vol. 11, Academic Press, Inc., New York, pp. 109-200.
- Klose, R. and Glicksman, M.: 1968, 'Gums' in *CRC Handbook of Food Additives*, Chemical Rubber Company, Cleveland, O., pp. 313-375.
- Lane, H., Catania A., and Stevens, S. S.: 1961, 'Voice Level: Autophonic Scale, Perceived Loudness, and the Effects of Sidetone', *J. Acoust. Soc. Am.* **33**, 160.
- Mackey, A.: 1958, 'Discernment of Taste Substances as Affected by Solvent Medium', *Food Res.* **23**, 580.
- Mackey A. and Vallassi, K.: 1956, 'The Discernment of Primary Tastes in the Presence of Different Food Textures', *Food Technol.* **10**, 238.
- Meiselman, H.: 1968, 'Adaptation and Cross-Adaptation of the Four Gustatory Qualities', *Perception & Psychophysics* **4**, 368.
- Moskowitz, H. R.: 1968, *Scales of Intensity for Single and Compound Tastes*, Unpublished Doctoral Dissertation, Harvard University.
- Moskowitz, H. R.: 1970a, 'Ratio Scales of Sugar Sweetness', *Perception & Psychophysics*, **7**, 315.
- Moskowitz, H. R.: 1970b, 'Sweetness and Intensity of Artificial Sweeteners', *Perception & Psychophysics*, **8**, 40.
- Panek, D. and Stevens, J.: 1965, 'PSYCHOFIT, a Computer Program for the Analysis of Psychophysical Data', Laboratory of Psychophysics, Harvard University, Report PPR 315.
- Stevens, S. S.: 1969, 'Sensory Scales of Taste Intensity', *Perception & Psychophysics* **6**, 302.
- Stone, H. and Oliver, S.: 1966, 'Effect of Viscosity on the Detection of Relative Sweetness Intensity in Sucrose Solutions', *J. Food Sci.* **31**, 129.
- Szczesniak, A.: 1963 'Objective Measurements of Food Texture', *J. Food Sci.* **28**, 410.
- Szczesniak, A. and Farkas, E.: 1962, 'Objective Characterization of the Mouthfeel of Gum Solutions', *J. Food Sci.* **27**, 381.
- Vaisey, M., Brunon, R., and Cooper, J.: 1969, 'Some Sensory Effects of Hydrocolloid Sols on Sweetness', *J. Food Sci.* **34**, 397.